NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 4016

SOME FACTORS AFFECTING THE VARIATION OF PITCHING MOMENT WITH SIDESLIP OF AIRCRAFT CONFIGURATIONS

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SUMMARY

A brief study of available wind-tunnel data with regard to the variation of pitching moment with sideslip has been made. The results indicate that the effect of sideslip on the pitching moment can be large and is dependent upon a large number of factors. For example, it was found that wing plan form, wing position, horizontal-tail location, aileron location, and fuselage shape can have appreciable effects on the pitching moment due to sideslip. However, data at large sideslip angles are rather meager and a considerable amount of systematic experimental data is needed, especially at transonic and supersonic speeds.

INTRODUCTION

Flight tests of aircraft having their mass concentrated primarily in the fuselage have indicated that during abrupt rolling maneuvers large uncontrollable motions can be encountered. These motions which are characterized by the attainment of extreme angles of attack and sideslip are associated primarily with the pitch-yaw divergence problem discussed in reference 1. Reference 1 presents a theoretical analysis that enables the prediction of the range of rolling velocity for which the airplane will diverge. In reference 2 calculated time histories of this type of motion are presented for various rolling velocities and it is shown that even for motions that are not divergent rather large variations in angle of attack and sideslip are encountered. These large variations are primarily due to the fact that an aircraft heavily loaded along the fuselage tends to roll about its principal axis and produce cyclic variations of angle of attack and sideslip. (See ref. 3.)

In order to predict the motions that might be encountered by an aircraft it is necessary to have estimates of its aerodynamic characteristics for a large range of angles of attack and sideslip. In this

[1]Supersedes declassified NACA Research Memorandum L55E20b by Edward C. Polhamus, 1955.

regard, calculations have indicated that in addition to the aerodynamic parameters usually considered the variation of pitching moment with sideslip, which quite often is neglected, can have a significant influence on the aircraft motions. However, with the exception of investigations of low-speed propeller-driven aircraft with their large slipstream effects (see ref. 4 for example), it appears that relatively little information with regard to the variation of pitching moment through large sideslip angles is available. Furthermore, much of the information that has been published has not been analyzed, inasmuch as it is usually presented only incidentally with respect to the usual lateral-stability data.

The purpose of this paper, therefore, is to summarize briefly wind-tunnel results regarding the effect of sideslip on the pitching moments. Because of a lack of sufficient data, the information contained herein can be considered only as illustrative of some of the more important factors affecting the variation of pitching moment with sideslip angle and as a possible guide to future systematic studies and correlations, rather than as a source of design information. In view of this fact, the ommission of the lift variations, which would be required for pitching-moment transfers, is believed to be justified. Inasmuch as little data are available at high subsonic and supersonic speeds, the results presented are, for the most part, limited to low subsonic speeds. Only a limited analysis is made and no attempts to estimate the various effects theoretically have been made.

SYMBOLS

The coefficients used herein are presented with respect to the stability system of axes. (See fig. 1.) All pitching moments are given about the 25-percent-chord point of the wing mean aerodynamic chord except where otherwise noted.

A aspect ratio, b^2/S_W

c_l section lift coefficient, $\frac{\text{Section lift}}{qc}$

c_n section normal-force coefficient,
$$\frac{\text{Normal force on two-dimensional cylinder per unit length}}{w \frac{\rho}{2} V_c^2}$$

C_L lift coefficient, $\frac{\text{Lift}}{qS_W}$

C_l	rolling-moment coefficient, $\frac{\text{Rolling moment}}{qS_wb}$
C_m	pitching-moment coefficient, $\frac{\text{Pitching moment}}{qS_w\bar{c}}$
q	free-stream dynamic pressure, $\frac{\rho V^2}{2}$, lb/sq ft
ρ	free-stream air density, slugs/cu ft
V	free-stream velocity, ft/sec
V_c	crossflow velocity, ft/sec
c	local wing chord, ft
c_{av}	average wing chord, ft
$\bar{c}$	wing mean aerodynamic chord, $\frac{2}{S_w}\int_0^{b/2} c^2dy$, ft
b	wing span, ft
S_w	wing area, sq ft
S_t	horizontal-tail area, sq ft
w	width of two-dimensional cylinder, ft
y	coordinate along Y-axis, measured from plane of symmetry
l_t	horizontal-tail length (distance between quarter-mean-aerodynamic-chord points of wing and tail), ft
η	nondimensional spanwise ordinate based on wing semispan, $\frac{y}{b/2}$
α	angle of attack, deg
β	angle of sideslip, deg
δ_a	aileron deflection (in plane perpendicular to hinge line), deg

Λ sweep of wing quarter-chord line, deg

λ taper ratio, $\frac{\text{Tip chord}}{\text{Root chord}}$

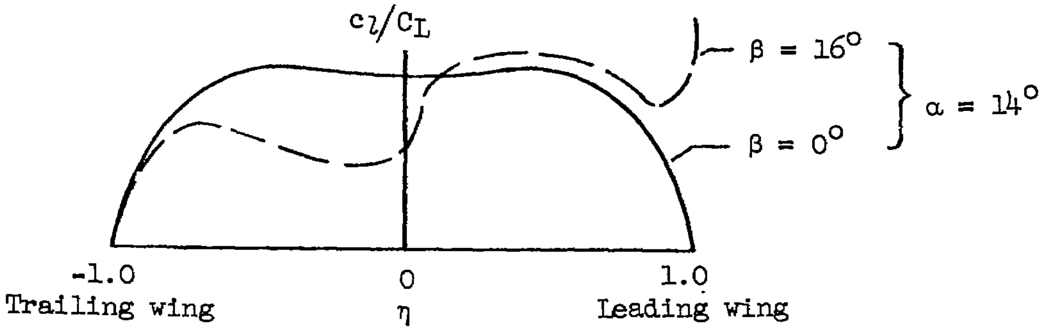
ϕ angle of flow incidence in plane normal to axis of two-dimensional cylinder or three-dimensional body

M Mach number

DISCUSSION

Wing Characteristics

Sweep effect.- Although relatively little experimental data through a range of sideslip angles are available for isolated wings, it appears that sweep has probably the largest effect on the wing-alone variation of pitching moment with sideslip. This is illustrated in figure 2 where the results are presented for wings of aspect ratio 5.2 having sweep angles of 0°, 30°, and 45° (from the systematic investigation reported in ref. 5) and for a 60° sweptback wing of aspect ratio 3.5 (ref. 6). The results for the three wings of the systematic series indicate that, although there is relatively little effect of sideslip angle on the pitching moments of the unswept wing, rather appreciable effects, consisting of negative increments of pitching moment due to sideslip, are present for the two moderately sweptback wings and these effects increase with increasing sweep angle. Pressure distributions have been obtained for these wings (see ref. 7) and the results indicate that for the sweptback wings the loss of lift on the trailing wing due to sideslip is considerably greater (especially at high sideslip angles) than the gain of lift on the leading wing and that the greatest portion of the loss occurs over the inboard portion of the wing (see sketch 1):

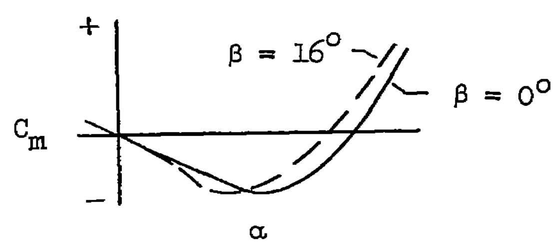


Sketch 1.

Since this inboard portion of the sweptback wing lies ahead of the aerodynamic center of the unsideslipped wing, a negative increment in pitching moment occurs due to sideslip. In addition, the results indicate that the largest portion of the gain in lift on the leading wing occurs at the tip which also results in a negative increment of pitching moment.

The main differences between the loadings of the leading and trailing wing can be explained by simple sweep theory (aspect-ratio effects neglected) which indicates that the loss of lift on the trailing wing is greater than the gain of lift on the leading wing, and by the fact that the center of load moves outboard with increasing sweep (sideslip in this case). It should be pointed out that the differences in loading between the leading and trailing wings actually are greater for wings of moderate sweep ($\Lambda = 30^{\circ}$) but because of the greater moment arms associated with the 45° wing the effect of sideslip on pitching moment is greater for this wing.

With regard to the 60° sweptback wing of aspect ratio 3.5 (lower right part of fig. 2), it will be noted that except for the angle of attack of 5.6° the effect of sideslip on the pitching moment is opposite that for the other wings. This is apparently due to the fact that this wing is the only one (of those presented) for which sideslip data were obtained above the angle of attack corresponding to pitch-up ($\alpha \approx 11^{\circ}$ for this wing). Since the pitch-up characteristics of sweptback wings occur at progressively lower angles of attack as the sweep angle increases (for example, see ref. 8), with the greatest change occurring in the high sweep range, it might be expected that, for a sweptback wing in sideslip, the change in the tip stalling would be more pronounced on the trailing wing and would result in a positive increment of pitching moment due to sideslip. This result is illustrated in sketch 2 which is based on data from reference 6:

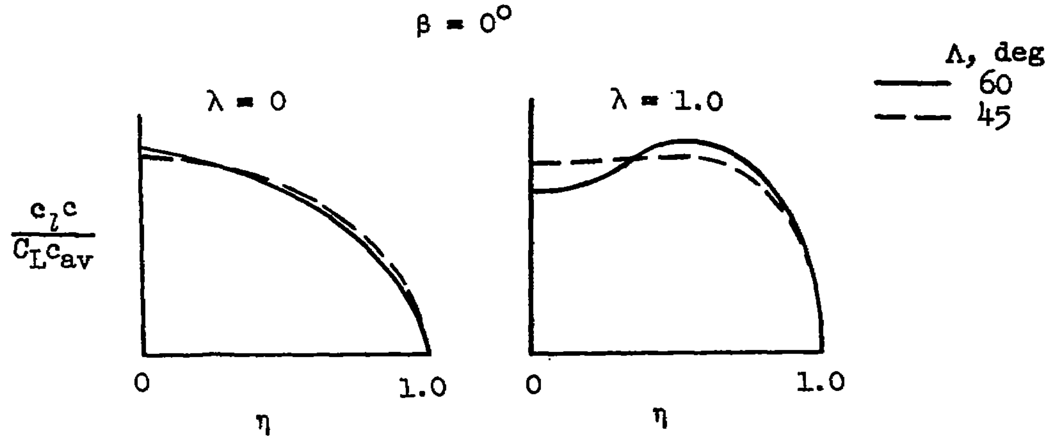


Sketch 2.

In sketch 2 the curves of pitching moment plotted against angle of attack are shown for the condition of a sideslip angle of 0° and a sideslip angle of 16°, and it will be noted that in the sideslipped condition the pitch-up occurs somewhat earlier and results in positive increments of pitching moment due to sideslip at the higher angles of attack.

Effect of taper and aspect ratio.- The effect of wing taper ratio on the variation of pitching moment with sideslip angle as determined from the systematic low-speed investigation reported in reference 5 is presented in figure 3 along with an indication of possible aspect-ratio effects.

With regard to taper ratio, the data indicate a considerable reduction in the variation of pitching moment with sideslip angle as the wings are made more highly tapered (lower value of taper-ratio parameter λ). Unfortunately no experimental pressure distributions appear to be available for the tapered wings. It would seem, however, that the reason for the negligible effect of sideslip on the highly tapered wing is associated with the fact that the effect of sweep angle on the span load distribution of unsideslipped wings decreases as the wings become more tapered (see ref. 9 and sketch 3):

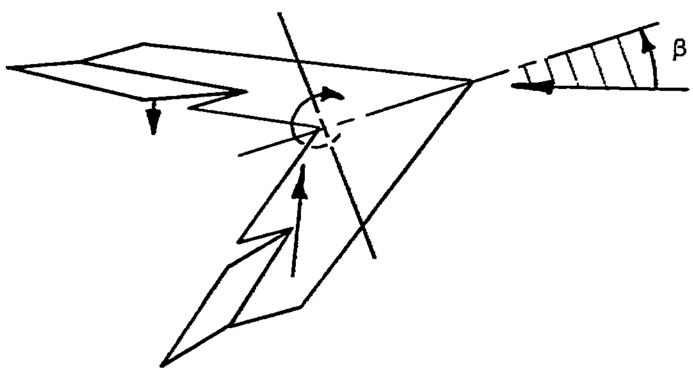


Sketch 3.

This fact suggests that, although there may be small variations of lift associated with sideslip, there probably is little change in the location of the load center for highly tapered wings and therefore little change in the pitching moment for a given angle of attack.

Considering the possible effect of aspect ratio on the variation of pitching moment with sideslip, it might be surmised that, inasmuch as the effect of wing sweep on the lift and span loading diminishes as the aspect ratio is reduced, the effect of sideslip on pitching moment would likewise diminish with decreasing aspect ratio. A comparison of the results for the wing of aspect ratio 5.2 (ref. 5) and a similar wing of aspect ratio 3.6 (ref. 10) is presented in the top part of figure 3 and appears to substantiate to some degree this reduction with decreasing aspect ratio; however, a systematic investigation over a larger range of aspect ratios is needed to define this effect fully.

Effect of ailerons.- The lift produced by high-lift flaps decreases with sideslip on a sweptback wing because there is a greater effect of sideslip on the lift of the flap on the trailing wing than on the leading wing, as discussed previously with regard to the wing alone. This, of course, will produce a variation with sideslip of the pitching moment produced by the flaps which will be dependent upon the flap location. However, a considerably greater effect might be expected from the deflection of ailerons. In the case of ailerons where one is deflected up and the other down, a variation of pitching moment with sideslip does not depend on the loss of lift on the trailing wing being greater than the gain on the leading wing. This is illustrated in sketch 4 for the condition of the wing at positive sideslip with the ailerons deflected to produce a negative roll:



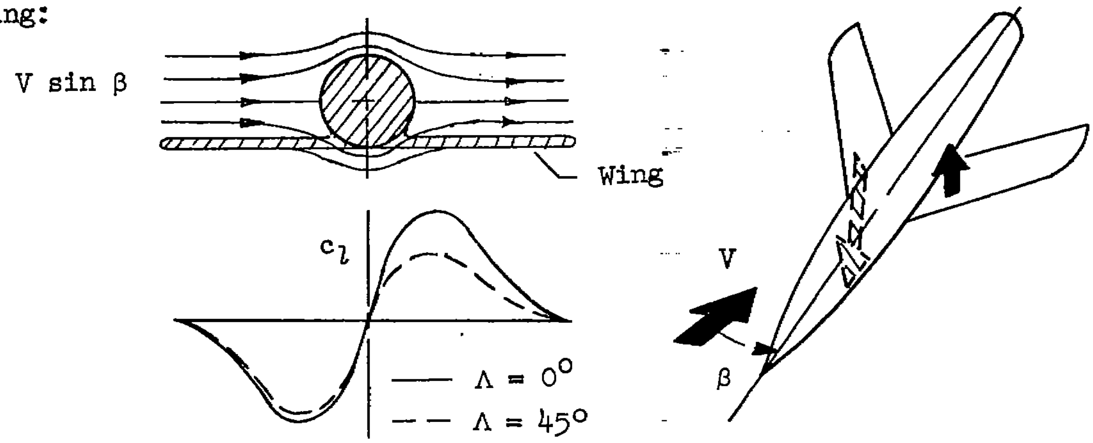
Sketch 4.

The aileron on the leading wing is producing positive lift which is increased by the sideslip (due to the lower effective sweep) while the aileron on the trailing wing is producing negative lift which is decreased in magnitude by the sideslip. The effects are additive with regard to C_m and cause (for the case illustrated) a negative pitching moment. Figure 4 presents results from reference 10 of experimentally determined (low-speed) variations of aileron-induced pitching moments with sideslip for 0°, 45°, and 60° sweptback wings at an angle of attack of approximately 0°. It will be noted that, as would be expected, there is relatively little effect of sideslip for the unswept wing, whereas there is an appreciable effect for the sweptback wings. It should be kept in mind that the results presented are for only one aileron and that with both ailerons deflected the rate of change with sideslip will be considerably increased.

Additional effects.- As mentioned previously, systematic investigations which include the effect of large angles of sideslip on the pitching moment are rather sparse and there are undoubtedly factors in addition to those discussed which might influence this effect. For example, large effects on swept wings might be expected between raked-forward and raked-back tips. Wing devices, such as those used to alleviate pitch-up tendencies, for example, would be expected to have an effect, as might changes in loading due to camber or profile shape. It should also be pointed out that, for the most part, the data presented have been for relatively low Reynolds numbers and that Reynolds number could have a noticeable effect, at least at the higher angles of attack where flow-separation effects can be important.

Wing-Body Characteristics

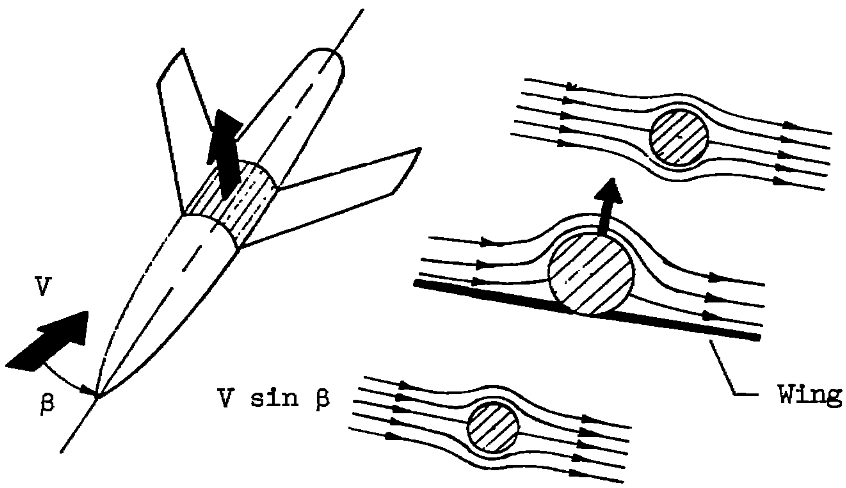
The discussion so far has dealt only with the wing-alone characteristics. However, the effect of sideslip on pitching moment is modified by the addition of a fuselage. For example, it appears (see ref. 6) that the addition of a fuselage to form a midwing configuration results in at least a slight decrease in sideslip effect. This effect, however, appears to be small compared to the effects of adding a fuselage to form a high- or low-wing configuration. The phenomena associated with wing height are thoroughly discussed by Jacobs in reference 11 and therefore only a brief summary will be presented here along with subsonic and supersonic experimental results. As pointed out in reference 11, there are three main factors contributing to the effect of wing height on the variation of pitching moment with sideslip. The first of these is dealt with in sketch 5 which illustrates the effect of the fuselage on the wing:



Sketch 5.

When a low wing is placed in the flow field of a fuselage in sideslip, the leading wing has negative lift induced by the flow field and the trailing wing has positive lift. For an unswept wing, these forces are of equal magnitude. However, for a sweptback wing, the trailing wing has greater sweep (by an increment equal to twice the sideslip angle) than the leading wing and therefore is less affected by the fuselage-induced angle, and the resulting asymmetrical load distribution produces an overall negative lift increment due to the fuselage flow field. Since this load is concentrated near the fuselage, it is usually forward of the unsideslipped aerodynamic center and therefore produces a negative pitching moment for sweptback wings in the low position and a positive pitching moment for sweptback wings in the high position.

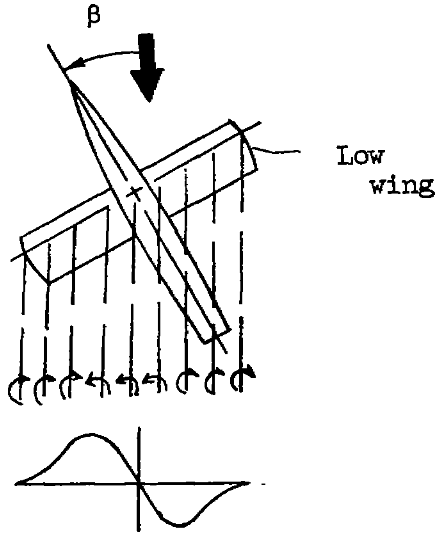
The second factor is illustrated as follows in sketch 6 and consists of the effect of the wing on the fuselage loads:



Sketch 6.

For a midwing position the cross flow about the fuselage is symmetrical; however, for a high or low wing the flow in the vicinity of the wing root chord is unsymmetrical as illustrated by sketch 6 (low wing). This flow would be expected to be somewhat similar to the flow about a cylinder with circulation and produces lift on the fuselage in the vicinity of the wing root (positive lift for low wing and negative lift for high wing). Calculations of this effect, of course, require that the position of the stagnation point be known. With low wings this fuselage load usually produces a positive pitching moment with increasing sideslip for sweptback wings and a negative moment for unswept wings.

The third factor is illustrated as follows in sketch 7 and consists of the effect on the fuselage of the wing downwash associated with wing height:



Sketch 7.

Sketch 7 illustrates the case of a low wing at positive sideslip. The spanwise distribution of the increment of load associated with the low wing, as previously discussed in connection with sketch 5, is shown along with the corresponding trailing vortices. In general, the fuselage will contribute a negative pitching-moment increment due to wing position for a low wing and a positive increment for a high wing. In connection with the downwash effect it should be pointed out that, for small values of wing span to body length (rearward of the wing) or for extremely large angles of sideslip, the downwash due to the angle-of-attack loading may be important and, of course, would exist even for a midwing location.

When these three effects are combined, the total increment of pitching moment due to sideslip caused by wing position is usually positive for high wings and negative for low wings. The overall effect of wing height as obtained experimentally at low subsonic speeds (ref. 11) for an unswept and sweptback wing is presented in figures 5 and 6 and the trends expected from the preceding concepts are clearly borne out. It should also be pointed out that in reference 11 good correlation with theoretical calculations based on these concepts is indicated.

Figure 7 presents the experimental effect of wing height on the variation of pitching moment with sideslip for a sweptback-wing configuration at a Mach number of 2.01. (Data were obtained from tests performed in the Langley 4- by 4-foot supersonic pressure tunnel.) The effect of wing height is somewhat similar to that obtained for the sweptback wing at low subsonic speeds (see fig. 6) except for the fact that the effect of sideslip for the midwing configuration is negligible.

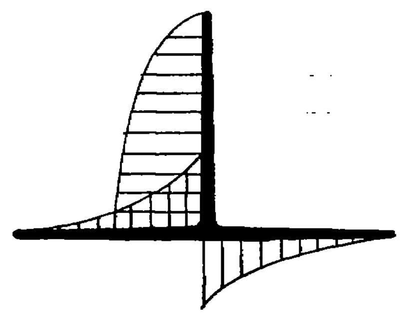
The discussion so far has dealt only with fuselages having circular cross sections and in order to illustrate the type of wing-height effects that might be encountered with noncircular fuselages some of the results of reference 12 are presented in figure 8. The results were obtained at low subsonic speeds on a configuration quite similar to that of figure 5 except that fuselages having triangular and rectangular cross sections were utilized. The results presented in figure 8 were obtained at an angle of attack of approximately 2° and indicate the effect of wing height on the variation of pitching-moment coefficient with sideslip angle for both fuselages to be quite similar to that obtained with a circular fuselage (fig. 5). Results presented in reference 13 for other fuselage cross sections although limited to complete configurations also indicate the effect of wing height to be relatively independent of fuselage cross section.

Although there is little or no information with regard to wing height at transonic speeds, it would appear, from the subsonic and supersonic results, that the trends would be similar to those presented herein. However, the magnitude of the wing-height effects is expected to be greatest in the transonic-speed range, inasmuch as the effect of sweep on lift is greatest at transonic speeds. (For example, see refs. 14 and 15.)

Horizontal-Tail Characteristics

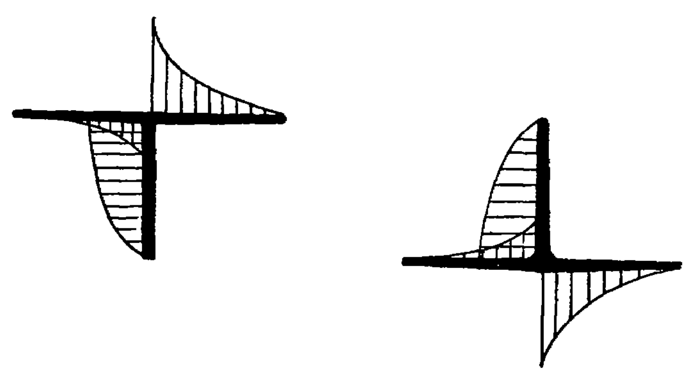
The direct effect of sideslip on the pitching moment contributed by the horizontal tail can be estimated with the aid of experimentally determined reduction in lift due to sideslip. Unfortunately, however, interference effects such as loads induced on the horizontal tail by the vertical tail and the fuselage flow field can be large. Although these effects are difficult to isolate with the experimental data that are available, an attempt will be made in the following sections to illustrate some of these effects.

<u>Vertical-tail effect</u>.- The vertical tail in sideslip induces loads on the horizontal tail. For small angles of sideslip the lift induced on the horizontal tail is negligible since the induced load distribution is essentially antisymmetrical (see ref. 16), as illustrated in sketch 8, and results in only a rolling moment:



Sketch 8.

Sketch 8 represents a condition of small positive sideslip with the horizontal tail in the low position. For a horizontal tail in the high position, the horizontal-tail loading would be reversed and a rolling moment of opposite sign would result but still essentially no net lift would be produced. At large angles of sideslip with swept horizontal tails, the loading will probably not be antisymmetrical mainly because of the difference in lift effectiveness of the leading and trailing portions of the horizontal tail caused by the difference in their effective sweep angles. This would result in a net lift induced on the horizontal tail which is a function of sideslip and tail height. This possible effect of tail height is illustrated in sketch 9 for large positive sideslip angles:

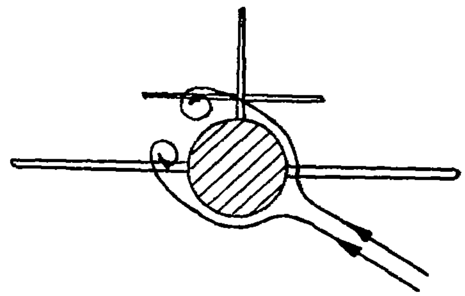


Sketch 9.

It will be noted that on the high horizontal tail a net positive lift is induced (sign of net lift is independent of direction of sideslip) which will result in a negative pitching moment, whereas the low tail will produce a negative lift and positive pitching moment. Some experimental evidence of the effect of the vertical tail for various horizontal-tail heights is presented in figure 9. The top part of the figure presents data obtained at a Mach number of 2.01 in the Langley 4- by 4-foot supersonic pressure tunnel for a complete configuration. The bottom two parts of the figure present results obtained in the Langley high-speed 7- by 10-foot tunnel for two body-tail configurations at a Mach number of 0.80. The pitching-moment coefficients for the body-tail configuration are based on wing dimensions which result in tail volumes $S_t l_t/S_w\bar{c}$ of 0.446 and 0.234 for the sweptback and delta tails, respectively. These compare with a value of 0.427 for the supersonic model. In order to isolate as well as possible the effect of horizontal-tail location on the vertical-tail interference, the data are presented at 0° angle of attack and, in the case of the complete configuration, for a midwing position. It will be noted that in all three cases the experimental results substantiate the expected trends (negative increments due to sideslip for high tails) and that the magnitude of the effect is rather large at sideslip angles greater than about 5°.

It should be kept in mind that other effect such as reductions (due to sideslip) of the loads on a tail deflected for longitudinal trim and differences in proximity of the leading and trailing portions of the horizontal tail to the vertical-tail flow field could also be important and that swept and unswept tails both would be suseptible to these effects.

Effect of fuselage flow field.- The wake characteristics of an aircraft configuration in sideslip can be influenced to a considerable extent by the fuselage. This, of course, can produce a large effect on the horizontal-tail contribution to the pitching moment due to sideslip. Some examples of this effect are shown in figures 10 and 11. Figure 10 presents low-speed pitching-moment data (ref. 17) and a wake-survey picture for an aircraft configuration. The wake-survey picture was made just to the rear of the horizontal-tail position by means of a tuft grid placed normal to the stream direction. (See ref. 18 for details of the tuft-grid technique.) For the tuft-grid picture the vertical and horizontal tails were removed and small-diameter circular rods were placed at three vertical positions on a vertical rod for orientation purposes, with the upper one corresponding to the top of the vertical tail and with the lower one on the bottom of the fuselage. The picture was taken at an angle of attack of 10° and an angle of sideslip of 25° and clearly shows, in addition to the wing-tip vortices, a strong (counterclockwise) vortex at the midtail location. The origin of this vortex was traced (by means of a tuft pole survey) to a point on the fuselage ahead of the canopy. It should be pointed out that tests with and without the canopy indicated little effect of the canopy on the fuselage vortex. It therefore appears that this vortex is associated with the well-known crossflow separation on bodies inclined to the wind. Although a second fuselage vortex would be expected to be produced somewhat below the one shown, it is not apparent in the flow picture. There is the possibility, however, that this vortex is intercepted, for this combination of angle of attack and sideslip, by the wing (see sketch 10) and through its effect on the wing loading is effectively distributed across the wing wake:



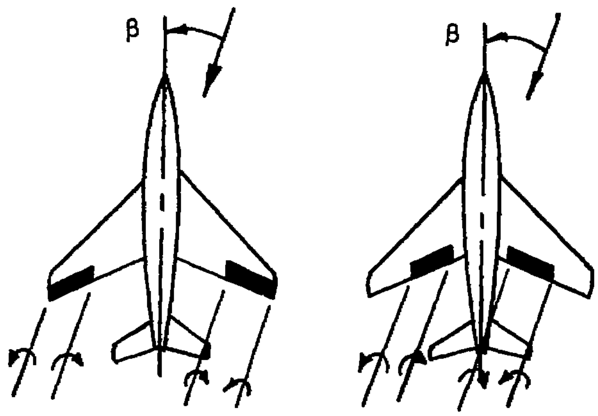
Sketch 10.

As the angle of sideslip increases from zero, the vortex increases in strength and moves away from the plane of symmetry. Both of these effects cause increases in the load induced on the horizontal tail by this vortex and can cause a considerable variation of pitching moment with sideslip. This is illustrated in figure 10 by the experimental pitching-moment data, for the configuration shown in the sketch, plotted as a function of sideslip angle for various angles of attack. Also shown is the horizontal-tail-off data for an angle of attack of 0.3°. The results indicate a large effect of sideslip on the tail contribution to the pitching moment which appears to be associated with the fuselage vortex. No definite conclusion with regard to the effect of angle of attack can be made inasmuch as tail-off data were obtained only at one angle of attack. Further evidence that this variation is associated with the fuselage vortex is contained in the fact that for this horizontal-tail location the vertical-tail effect (see the previous section) would be either in the opposite direction or negligble.

Figure 11 presents somewhat similar results (ref. 19) obtained for a fuselage-tail configuration (wing off) at low subsonic speed. Here again the horizontal tail is in a location where the vertical-tail effect would be expected to result in positive increments of the tail contribution due to sideslip, but negative increments result at an angle of attack of 0.2° apparently from the fuselage-vortex effect. At an angle of attack of 22.2° it will be noted that the variation with sideslip angle was reversed. A large reduction in the sideslip effect would be expected at this angle of attack inasmuch as it is on the flat portion of the tail lift curve. The actual reversal of sideslip effect that occurs may be due to the effect of the vertical tail on the horizontal tail (see fig. 9).

Inasmuch as the preceding experimental results have indicated a strong effect of fuselage vortices on the variation of pitching moment with sideslip angle, it appears that information with regard to the effect of fuselage shape on the origin, strength, and path of these vortices is urgently needed. With regard to these fuselage vortices the reader is referred to reference 20 which presents a preliminary study of their effect on tail loads for relatively simple body shapes.

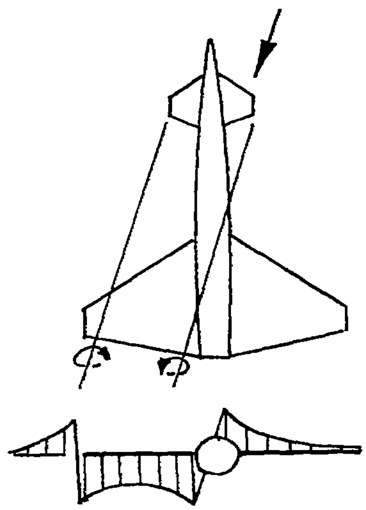
Aileron effect.- It was shown in the section "Wing Characteristics" that ailerons can have a rather sizable effect on the variation with sideslip of the pitching-moment coefficient of swept wings. (See fig. 4.) However, in addition to this effect the ailerons can, for certain configurations at least, have a large effect on the variation of the horizontal-tail pitching-moment contribution with sideslip. Some results of a recent investigation of this effect conducted in the Langley 300-MPH 7- by 10-foot tunnel are presented in figure 12. The model consisted of a 45° sweptback wing of aspect ratio 4.0 having a taper ratio of 0.3 and NACA 65A006 airfoil sections parallel to the plane of symmetry mounted in the midwing position on a body of revolution, a 45° sweptback horizontal tail mounted on the fuselage center line, and a 45° sweptback vertical tail. Both inboard and outboard ailerons were investigated and the results are presented for the condition of the right aileron deflected down 10° and the left up 10° (producing left roll). Tail-off results are presented in the lower portion of figure 12 for an angle of attack of 6.5° for the inboard ailerons (no tail-off data obtained for outboard ailerons). The tail-off results are in agreement with the previously discussed aileron effects. (See fig. 4.) In the middle portion of figure 12 the tail-on results are shown for an angle of attack of 6.5° and for the undeflected aileron the low-tail effect shown in figure 9 is in evidence. With the inboard ailerons deflected it will be noted that the aileron effect is opposite to what it was with the horizontal tail off; that is, with the tail on the inboard ailerons contribute a positive increment of pitching moment for positive sideslip angles. It will be further noted that, with the outboard ailerons deflected, negative pitching-moment increments are produced. This large effect of aileron location is apparently associated with the relationship between the horizontal tail and the aileron downwash field. This is illustrated as follows in sketch 11 which compares inboard and outboard ailerons at a sideslip angle of about 20°:



Sketch 11.

The vortex system respresents ailerons deflected so as to produce a negative rolling moment. It will be noted that the tail pitching moments induced by the aileron flow field would be expected to be of opposite sign for this particular combination of aileron location and sideslip angle with the outboard ailerons contributing a negative moment and the inboard a positive moment. Returning now to figure 12, the results at an angle of attack of 12.7° indicate that the effect of aileron deflection has reduced somewhat because the low tail has moved somewhat below the aileron wake. This implies that the effect of aileron deflection on the tail increment of pitching moment will depend upon the horizontal-tail location in addition to the aileron location and the angle of attack.

Canard configurations.- The effects discussed in the previous section apply for the most part to conventional-tail configurations. The purpose of this section, therefore, is to provide an indication of the type of variation of pitching moment with sideslip that might be encountered with a canard configuration and to illustrate the effect of various individual components. Low-speed wind-tunnel results obtained in the Langley 300-MPH 7- by 10-foot tunnel are presented in figure 13 along with a sketch of the configuration. The tests were obtained at an angle of attack of 10° with the canard control deflected 10°. As might be expected, in view of the moderate wing sweep, the wing-fuselage combination encountered only a slight variation of pitching moment with sideslip. However, for the fuselage—canard-control configuration a rather appreciable variation of pitching moment with sideslip was encountered. It is of interest to note that the decrease in pitching moment with increasing sideslip that might be expected was confined to the higher sideslip angles and that an increase occurred for angles up to about 23°. This may be associated to some extent at least with an effect of sideslip on the body-induced upwash encountered by the relatively small surfaces. Separation can change the crossflow velocity distribution so that the change in orientation of the crossflow velocity due to sideslip, which can be neglected in potential flow, must be considered (even for the midposition) in determining the overall upwash effect. The effect of the canard control on the variation of pitching moment with sideslip is reflected to some extent in the wing—fuselage—canard-control configuration, although the variations at the higher sideslip angles are somewhat reduced. This may be associated with the fact that at high sideslip angles the upwash outboard of the trailing portion of the canard control no longer is intercepted by the wing and an increase in overall downwash (see sketch 12) might therefore be expected which would tend to counteract to some extent the direct canard-control moments:



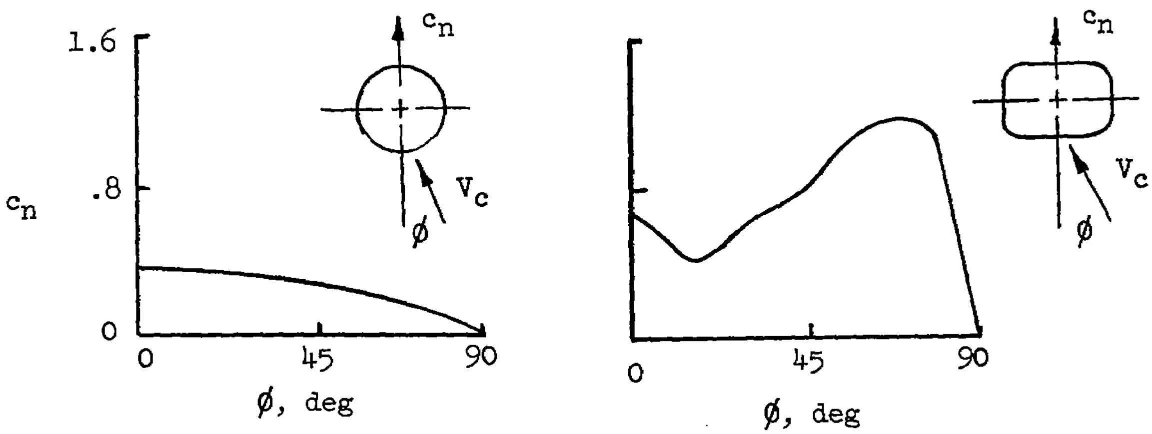
Sketch 12.

(Typical canard-control flow fields at supersonic speeds can be seen in ref. 21.) Finally, it should be noted that the addition of the vertical tail has a rather sizable effect on the variation of pitching moment with sideslip. Additional tests indicated that this effect of the vertical tail did not exist for the configuration with the canard control off. Thus, the possibility exists that the vertical-tail pressure field may be influencing the canard-control interference on the wing.

Even though the results of this investigation indicate that rather sizable effects of the canard control might be encountered, it does not appear possible to arrive at any general conclusion with regard to canard configurations because of the rather large number of interference effects that appear to be involved and the meager information available.

Flat Fuselages

The trend toward long fuselages and relatively small wings, dictated by performance requirements, has appreciably increased the proportion of lift carried by the fuselage. This is especially true for fuselages having relatively flat cross sections, and under certain conditions it appears that rather large variations in the lift of these fuselages could accompany variations in sideslip angle which, of course, may result in appreciable variations of pitching moment with sideslip. In order to provide basic information from which the effects of fuselage cross-sectional shape might be predicted, an investigation of the aerodynamic characteristics of several noncircular two-dimensional cylinders has been made and is reported in reference 22. Application of this two-dimensional data to the prediction of the side force and spinning characteristics of fuselages by means of the well-known "crossflow" concept is illustrated in reference 22 and the reasonable correlation obtained indicates that the effect of fuselage cross section on the pitching moment due to sideslip might also be estimated by this method. The method is illustrated in sketch 13 in which the section normal-force coefficient c_n for a circular and a modified rectangular two-dimensional cylinder is presented as a function of the flow incidence angle ϕ:



Sketch 13.

The angle ϕ is related to the flow incidence in the crossflow plane of a fuselage at combined angles of attack and sideslip by the following equation:

$$\tan \phi = \frac{\tan \beta}{\tan \alpha}$$

which is given in reference 22. For a constant angle of attack, increasing ϕ corresponds to increasing β. The curves represent the variation for a constant value of crossflow velocity V_c, and it will be noted that although the force on the circular cylinder continuously decreases as the cosine of the flow incidence, the force for the flat rectangular cylinder increases rather rapidly in the range of ϕ from approximately 15° to 70°. This is apparently due to the fact that as the angle is increased the flow begins to attach on the top of the cylinder and it becomes a lifting surface. In applying this data it must be kept in mind that at a constant angle of attack the crossflow velocity will increase with sideslip (or ϕ) and that therefore the variation of normal-force coefficient will be considerably greater than indicated in sketch 13. From these results it appears that flat fuselages might be expected to experience a considerable variation in lift with changes in sideslip angle. Since the fuselage rearward of the center of gravity usually experiences a reduction in flow angle due to the wing downwash and quite often is considerably blanketed by the wing and tail, these lift variations may be concentrated on the portion of the fuselage ahead of the wing and thereby produce considerable variation in pitching moment with sideslip.

CONCLUDING REMARKS

It is evident from this study that the variation of pitching moment with sideslip angle can be large and that it depends upon a large number of variables. Although data are rather meager, it appears that several rather definite conclusions can be determined from this information with regard to the effect of these variables. For example, it appears that negative increments of pitching moments due to positive sideslip angles are asociated with wing sweep (below the angle of attack for pitch-up), low wing position, high horizontal-tail location (relative to vertical tail), fuselage vortices, and outboard ailerons producing negative roll. However, considerably more experimental information is needed with regard to the effect of sideslip on pitching moment, especially at transonic and supersonic speeds, for large sideslips and angles of attack.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., May 2, 1955.

REFERENCES

1. Phillips, William H.: Effect of Steady Rolling on Longitudinal and Directional Stability. NACA TN 1627, 1948.

2. Sternfield, Leonard: A Simplified Method for Approximating the Transient Motion in Angles of Attack and Sideslip During a Constant Rolling Maneuver. NACA RM L56F04, 1956.

3. Stone, Ralph W., Jr.: An Analytical Study of Sideslip Angles and Vertical-Tail Loads in Rolling Pullouts As Affected by Some Characteristics of Modern High-Speed Airplane Configurations. NACA RM L53G21, 1953.

4. Rogallo, Francis M., and Swanson, Robert S.: Wind-Tunnel Tests of a Twin-Engine Model To Determine the Effect of Direction of Propeller Rotation on the Static-Stability Characteristics. NACA WR L-295, 1943. (Formerly NACA ARR, Jan. 1943.)

5. Jacobs, W.: Systematische Sechskomponentenmessungen an Pfeilflügeln. Bericht 44/21, Aerodynamisches Institut der T. H. Braunschweig, Sept. 4, 1944.

6. McCormack, Gerald M., and Walling, Walter C.: Aerodynamic Study of a Wing-Fuselage Combination Employing a Wing Swept Back 63°. - Investigation of a Large-Scale Model at Low Speed. NACA RM A8D02, 1949.

7. Jacobs, W.: Systematische Druckverteilungsmessungen an Pfeilflügeln konstanter Tiefe bei symmetrischer und unsymmetrischer Anströmung. Bericht 44/28, Aerodynamisches Institut der T. H. Braunschweig, Nov. 8, 1944.

8. Goodman, Alex, and Brewer, Jack D.: Investigation at Low Speeds of the Effect of Aspect Ratio and Sweep on Static and Yawing Stability Derivatives of Untapered Wings. NACA TN 1669, 1948.

9. DeYoung, John, and Harper, Charles W.: Theoretical Symmetric Span Loading at Subsonic Speeds for Wings Having Arbitrary Plan Form. NACA Rep. 921, 1948.

10. Letko, William, and Goodman, Alex: Preliminary Wind-Tunnel Investigation at Low Speed of Stability and Control Characteristics of Swept-Back Wings. NACA TN 1046, 1946.

11. Jacobs, W.: Lift and Moment Changes Due to the Fuselage for a Yawed Aeroplane With Unswept and Swept Wings. Rep. No. 34, Aero. Res. Inst. of Sweden (Stockholm), 1950.

12. Ksoll, R.: Experimentelle Untersuchungen an "Fluegel + Rumpf" Anordnungen mit Ruempfen von Birnenfoermigem und Rechteckaehnlichem Querschnitt. Ber. No. 45/14, Institut für Strömungsmechanik der Tech. H. S. Braunschweig, July 1946.

13. Letko, William: Experimental Investigation at Low Speed of the Effects of Wing Position on the Static Stability of Models Having Fuselages of Various Cross Section and Unswept and 45° Sweptback Surfaces. NACA TN 3857, 1956.

14. Polhamus, Edward C.: Summary of Results Obtained by Transonic-Bump Method on Effects of Plan Form and Thickness on Lift and Drag Characteristics of Wings At Transonic Speeds. NACA TN 3469, 1955. (Supersedes NACA RM L51H30.)

15. Lowry, John G., and Polhamus, Edward C.: A Method for Predicting Lift Increments Due to Flap Deflections at Low Angles of Attack at Incompressible Flow. NACA TN 3911, 1957.

16. Queijo, M. J., and Riley, Donald R.: Calculated Subsonic Span Loads and Resulting Stability Derivatives of Unswept and 45° Sweptback Tail Surfaces in Sideslip and in Steady Roll. NACA TN 3245, 1954.

17. Sleeman, William C., Jr., and Alford, William J., Jr.: Low-Speed Investigation of the Effects of Wing Tanks and Speed Brakes on the Static Stability of a Model Having a 40° Swept Wing. NACA RM L55C17, 1955.

18. Bird, John D., and Riley, Donald R.: Some Experiments on Visualization of Flow Fields Behind Low-Aspect-Ratio Wings by Means of a Tuft Grid. NACA TN 2674, 1952.

19. Kemp, William B., Jr., and Becht, Robert E.: Stability and Control Characteristics at Low Speed of a 1/4-Scale Bell X-5 Airplane Model. Lateral and Directional Stability and Control. NACA RM L50C17a, 1950.

20. Stone, Ralph W., Jr., and Polhamus, Edward C.: Some Effects of Shed Vortices on the Flow Fields Around Stabilizing Tail Surfaces. Presented to Structures and Materials Panel of AGARD (Copenhagen, Denmark), Apr. 29 - May 4, 1957.

21. Fradenburgh, Evan A., Obery, Leonard J., and Mello, John F.: Influence of Fuselage and Canard-Type Control Surface on the Flow Field Adjacent to a Rearward Fuselage Station at a Mach Number of 2.0. Data Presentation. NACA RM E51K05, 1952.

22. Polhamus, Edward C.: Effect of Flow Incidence and Reynolds Number on Low-Speed Aerodynamic Characteristics of Several Noncircular Cylinders With Applications to Directional Stability and Spinning. NACA TN 4176, 1958.

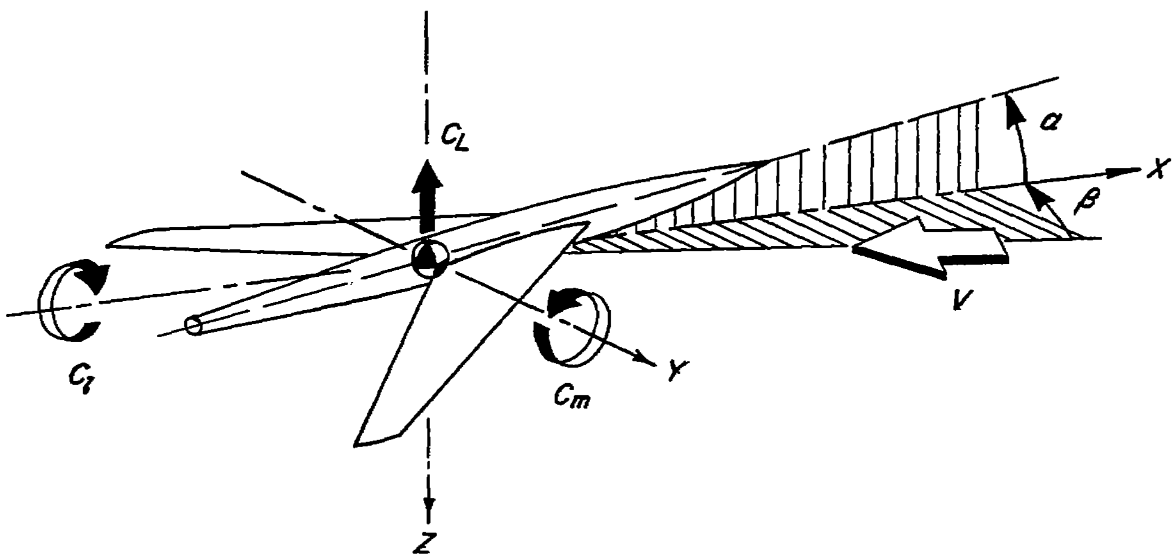


Figure 1.- System of axes used (stability) showing positive direction of forces, moments, and angles.

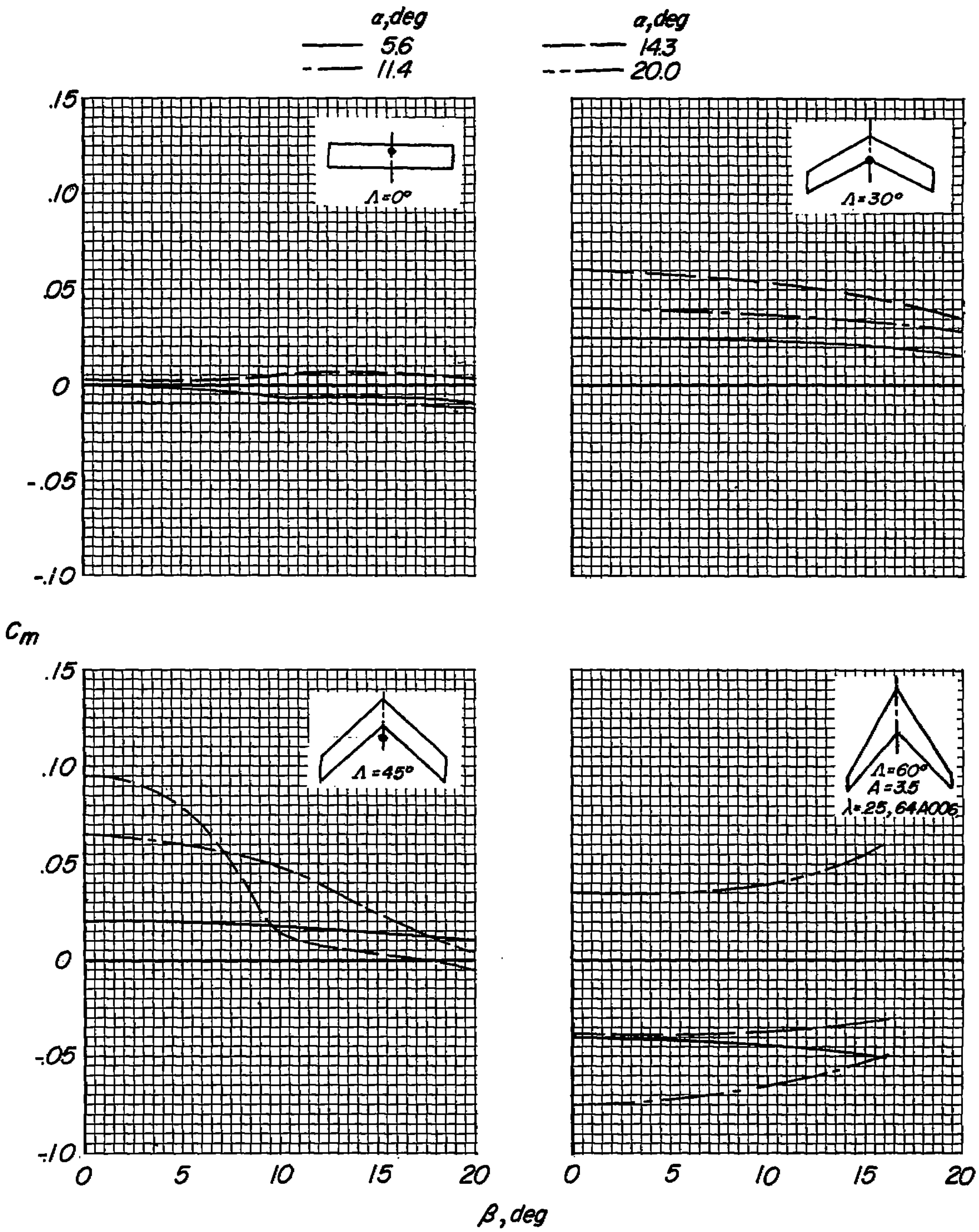


Figure 2.- The variation of pitching-moment coefficient with sideslip angle for various sweptback wings at low subsonic speeds. A = 5.2; λ = 1.0; NACA 23012 airfoil section (except where noted).

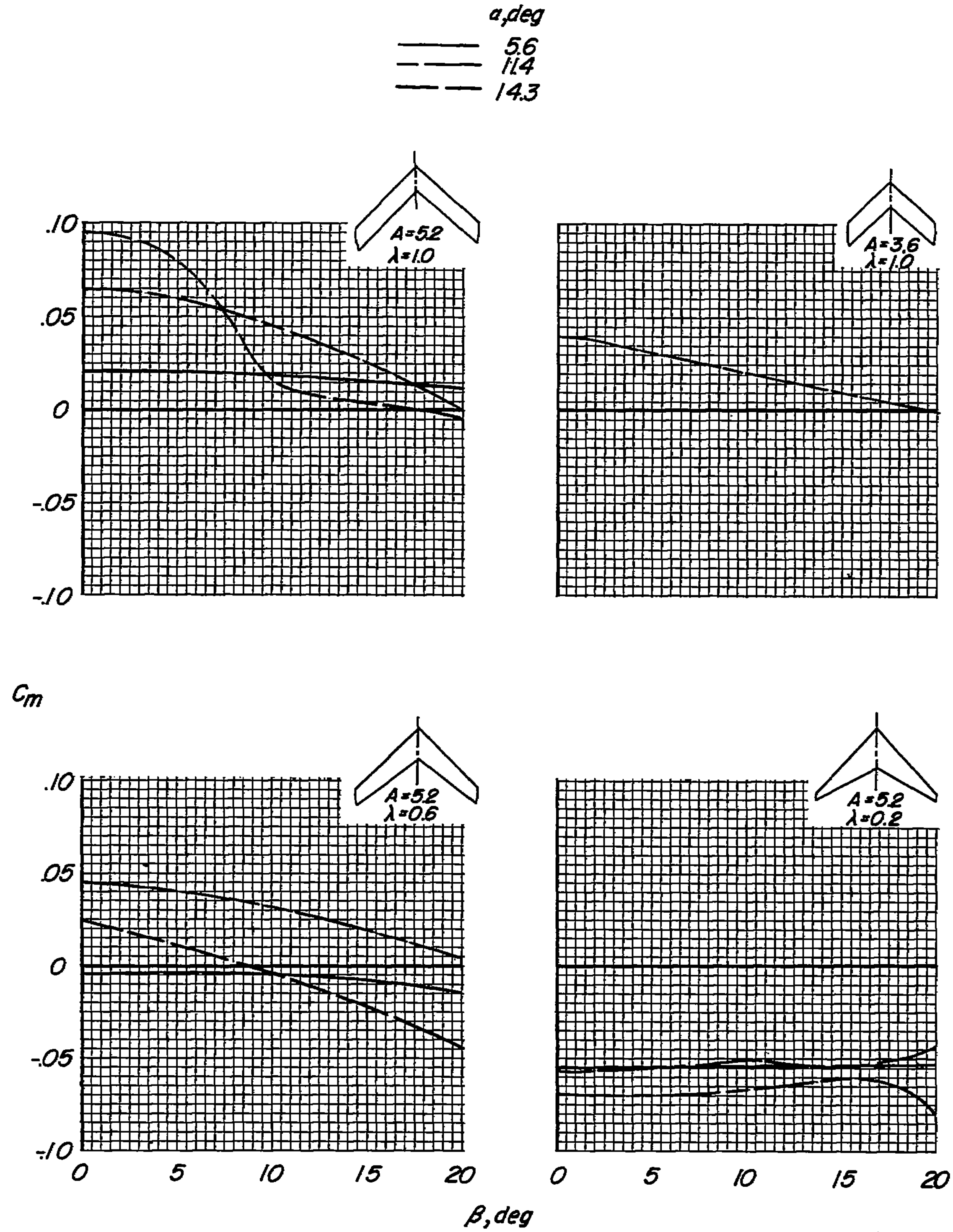


Figure 3.- The variation of pitching-moment coefficient with sideslip angle for wings of various aspect ratios and taper ratios at low subsonic speeds. Λ = 45°; NACA 23012 airfoil section.

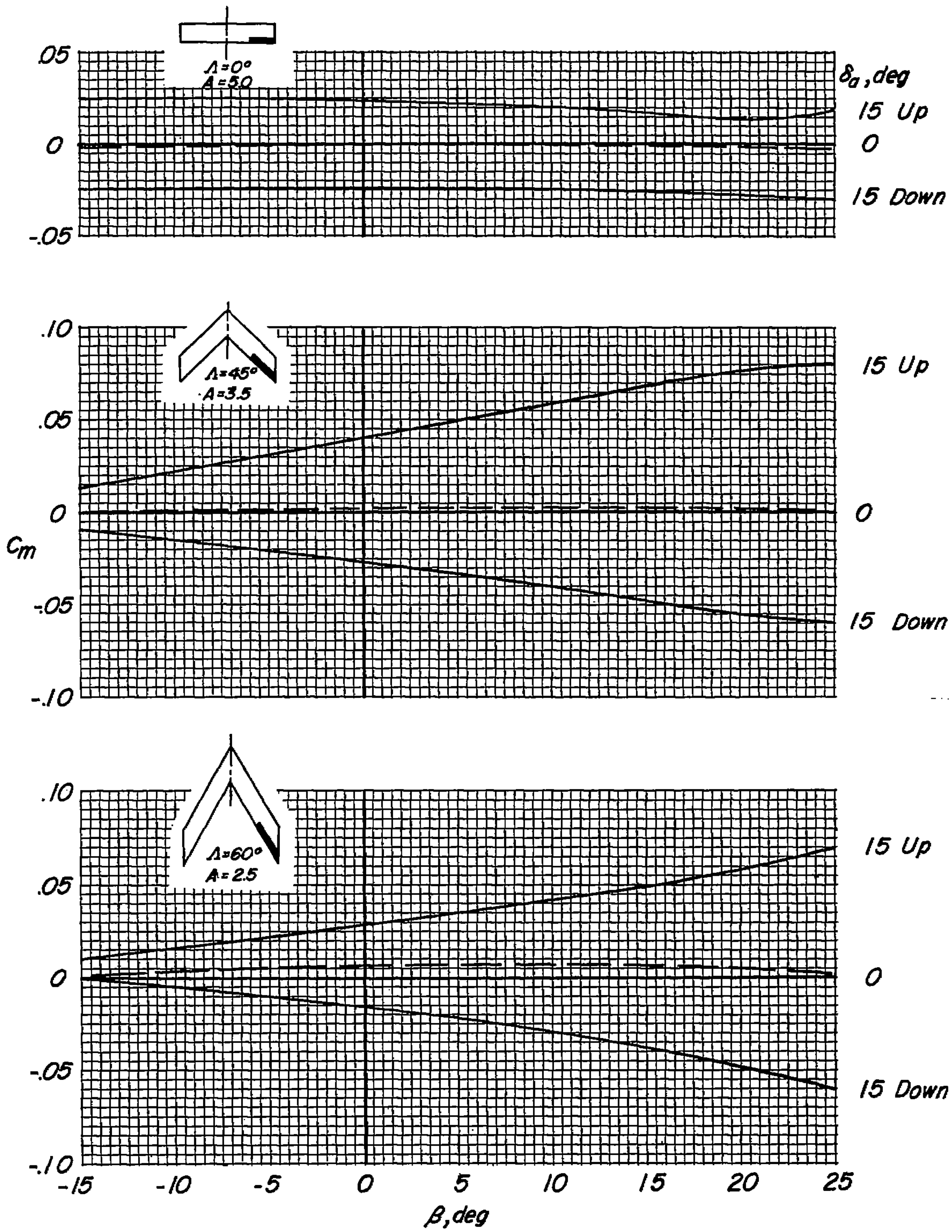


Figure 4.- Effect of right-aileron deflection on the variation of pitching-moment coefficient with sideslip angle for various swept wings at low subsonic speeds. $\lambda = 1.0$; $\alpha \approx 0^{\circ}$.

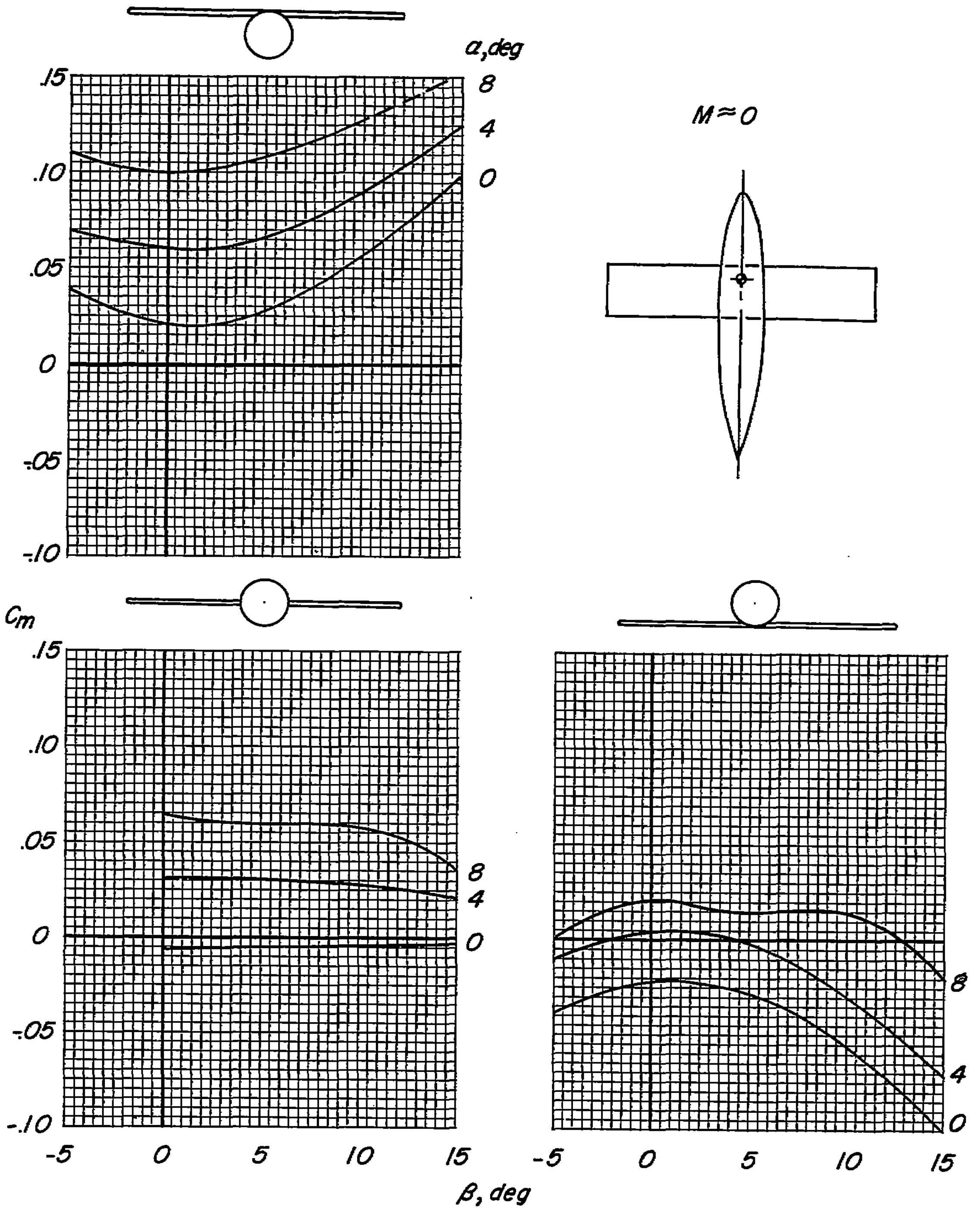


Figure 5.- Variation of pitching-moment coefficient with sideslip angle for various wing vertical positions at low subsonic speeds. $\Lambda = 0^{\circ}$; $A = 5$; $\lambda = 1.0$.

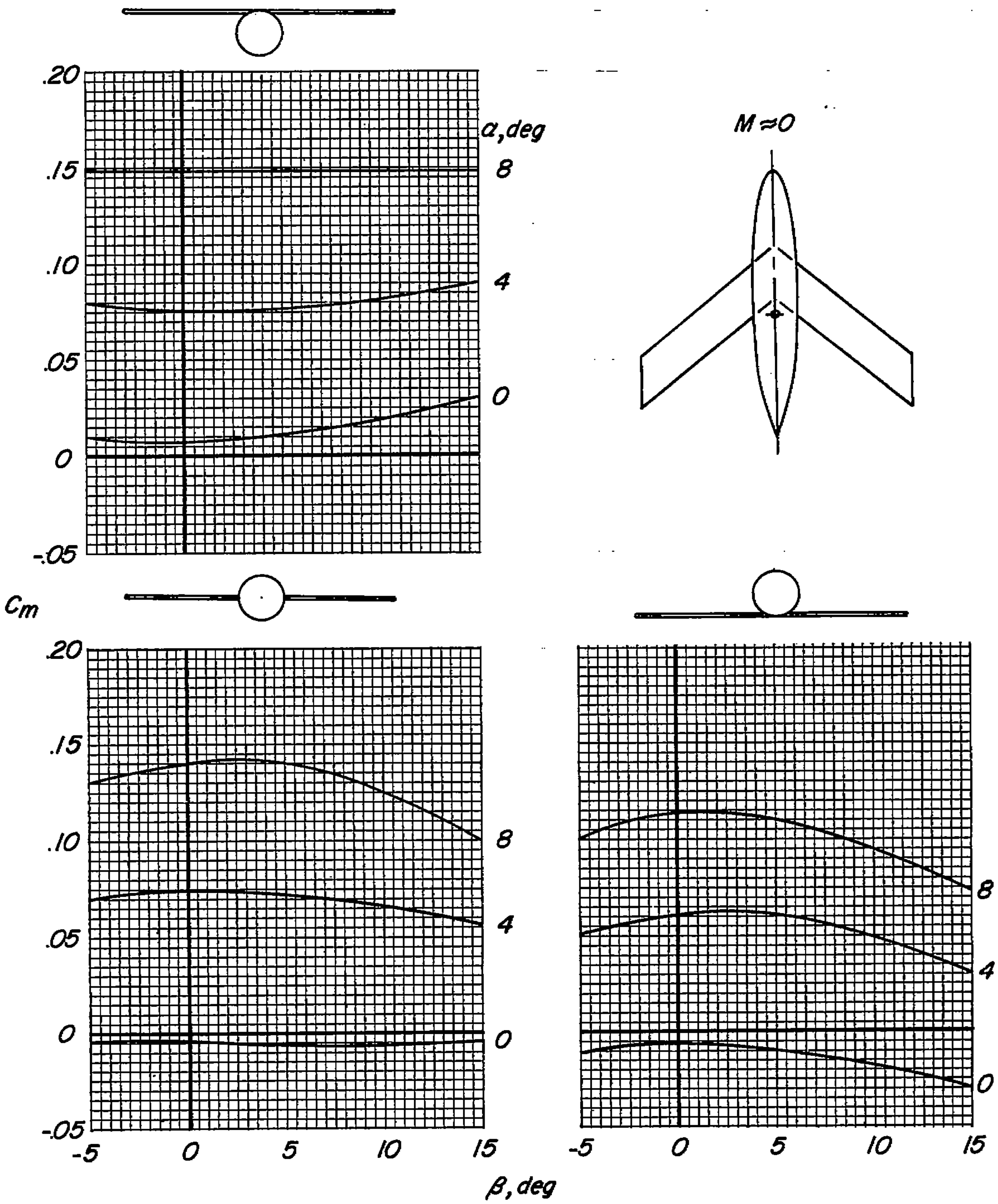


Figure 6.- Variation of pitching-moment coefficient with sideslip angle for various wing vertical positions at low subsonic speeds. $\Lambda = 45^{\circ}$; $A = 5$; $\lambda = 1.0$.

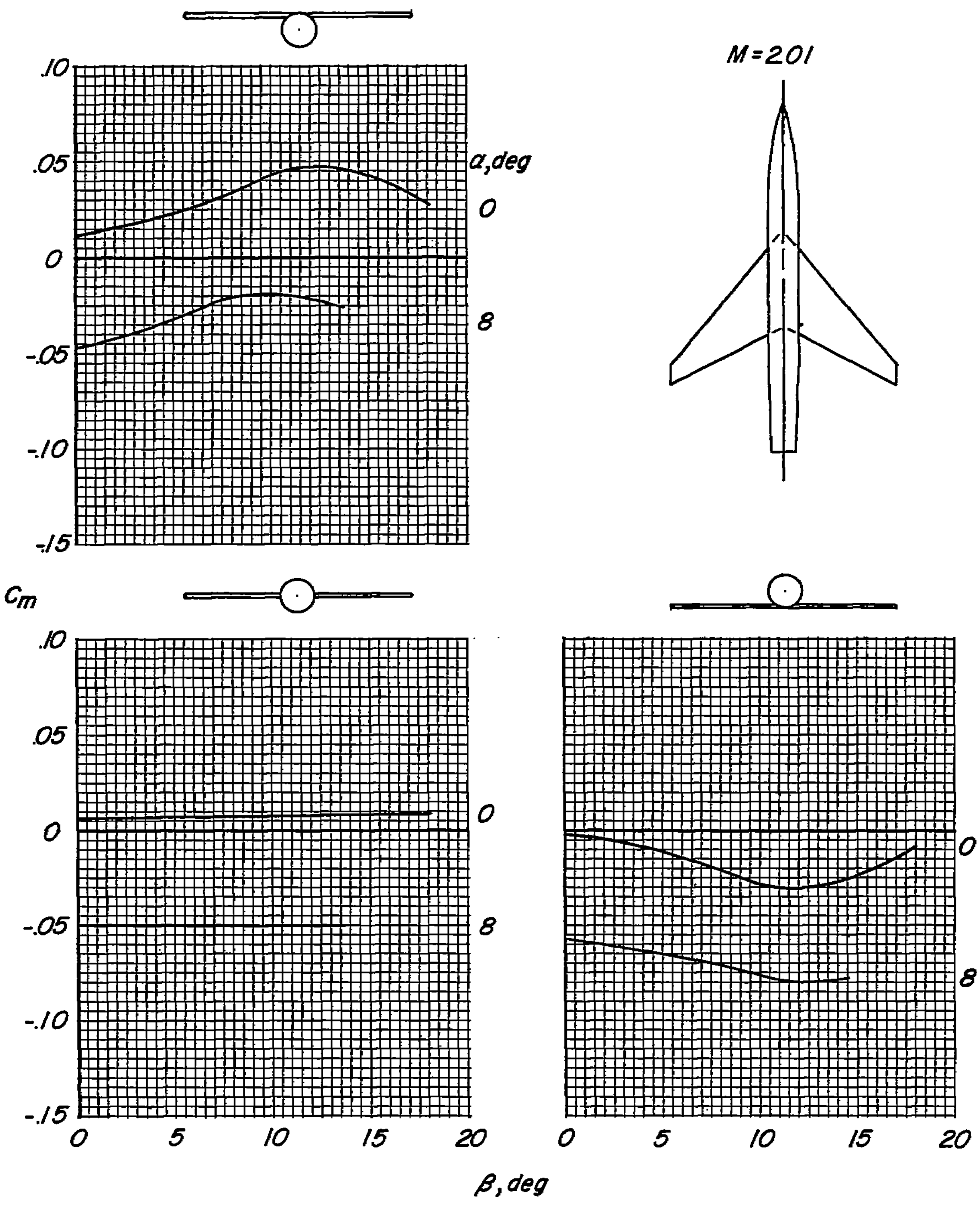


Figure 7.- Variation of pitching-moment coefficient with sideslip angle for various wing vertical positions at a Mach number of 2.01. $\Lambda = 45^{\circ}$; $\lambda = 0.2$; NACA 65A004 airfoil section.

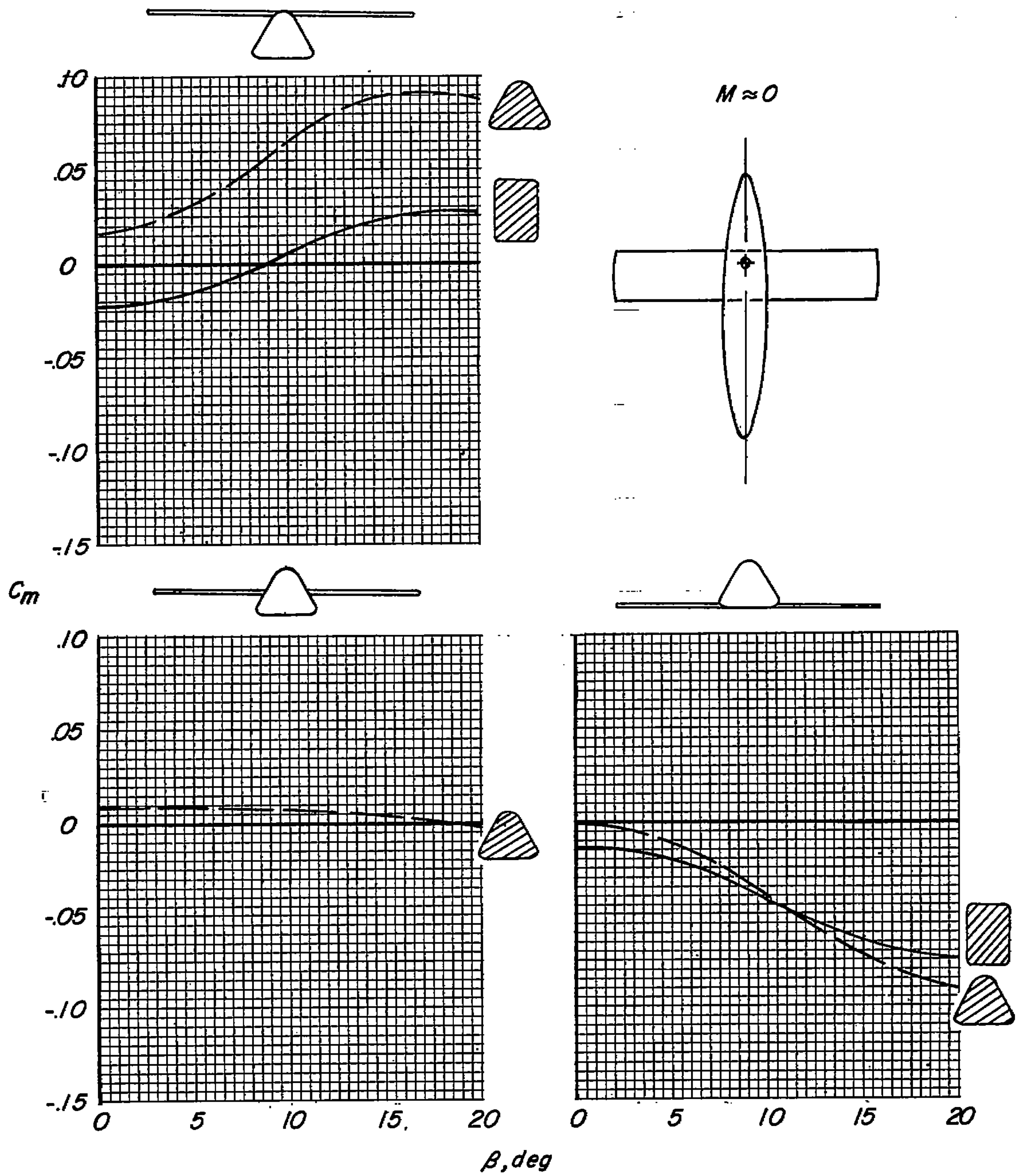


Figure 8.- Effect of fuselage cross section and wing vertical position on the variation of pitching-moment coefficient with sideslip angle at low subsonic speeds. $\Lambda = 0$; $A = 5.15$; $\lambda = 1.00$; $\alpha = 1.9^{\circ}$.

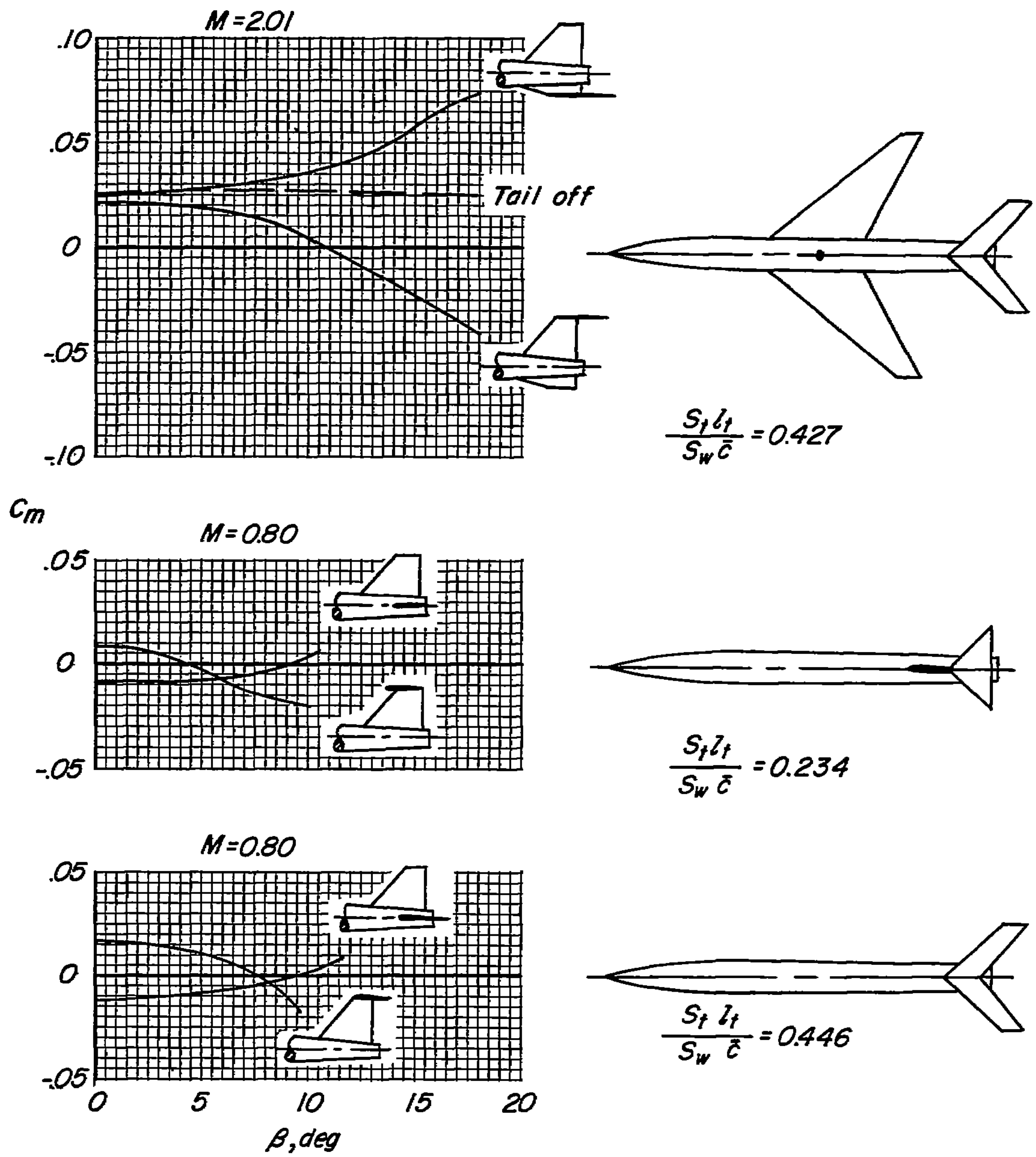


Figure 9.- Variation of pitching-moment coefficient with sideslip angle for various horizontal-tail positions. $\alpha = 0^{\circ}$.

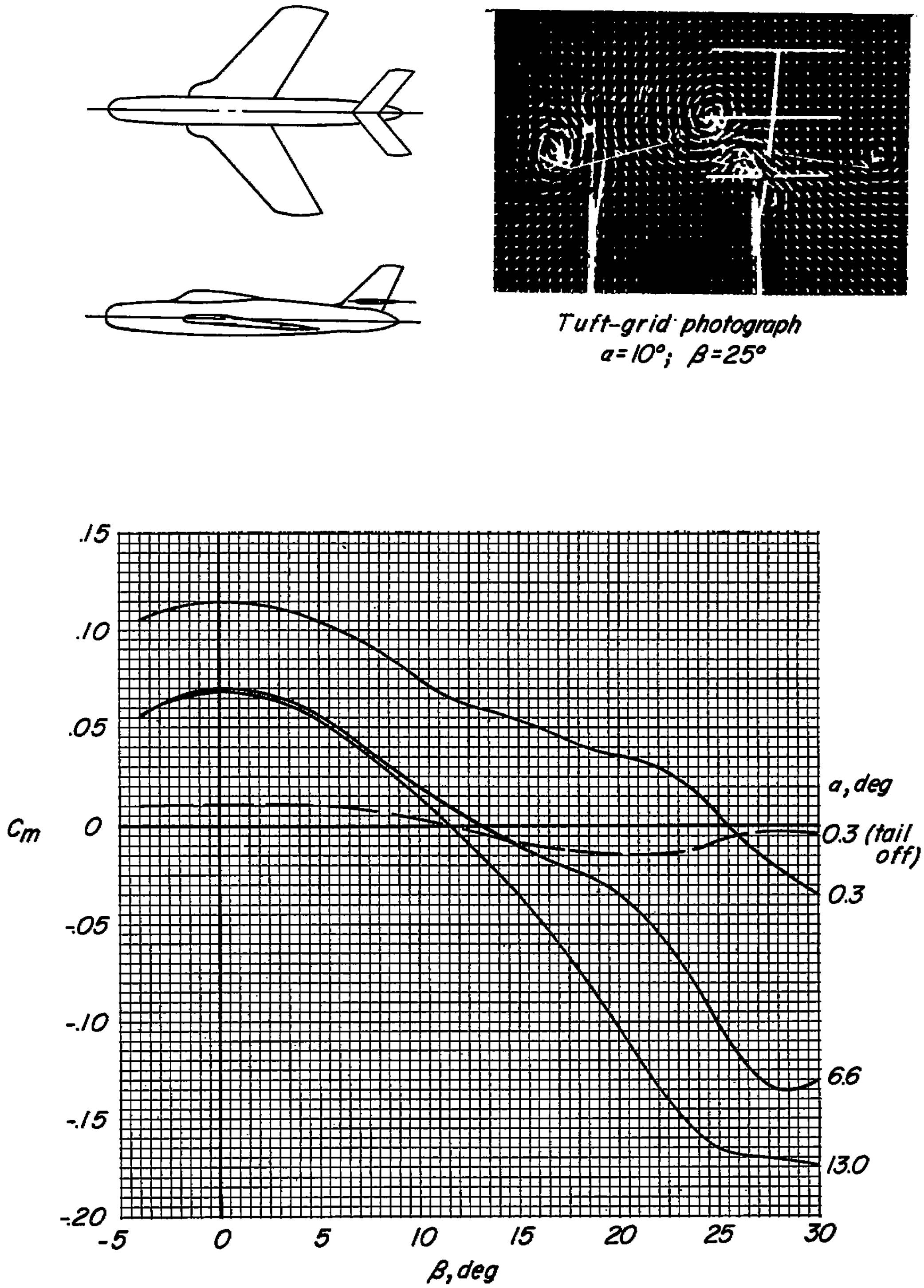
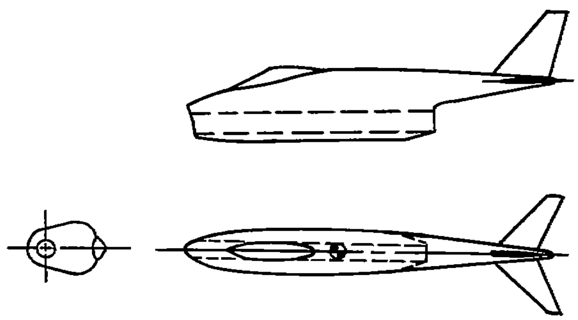


Figure 10.- Effect of fuselage vortex on the variation of pitching-moment coefficient with sideslip angle at low subsonic speeds.



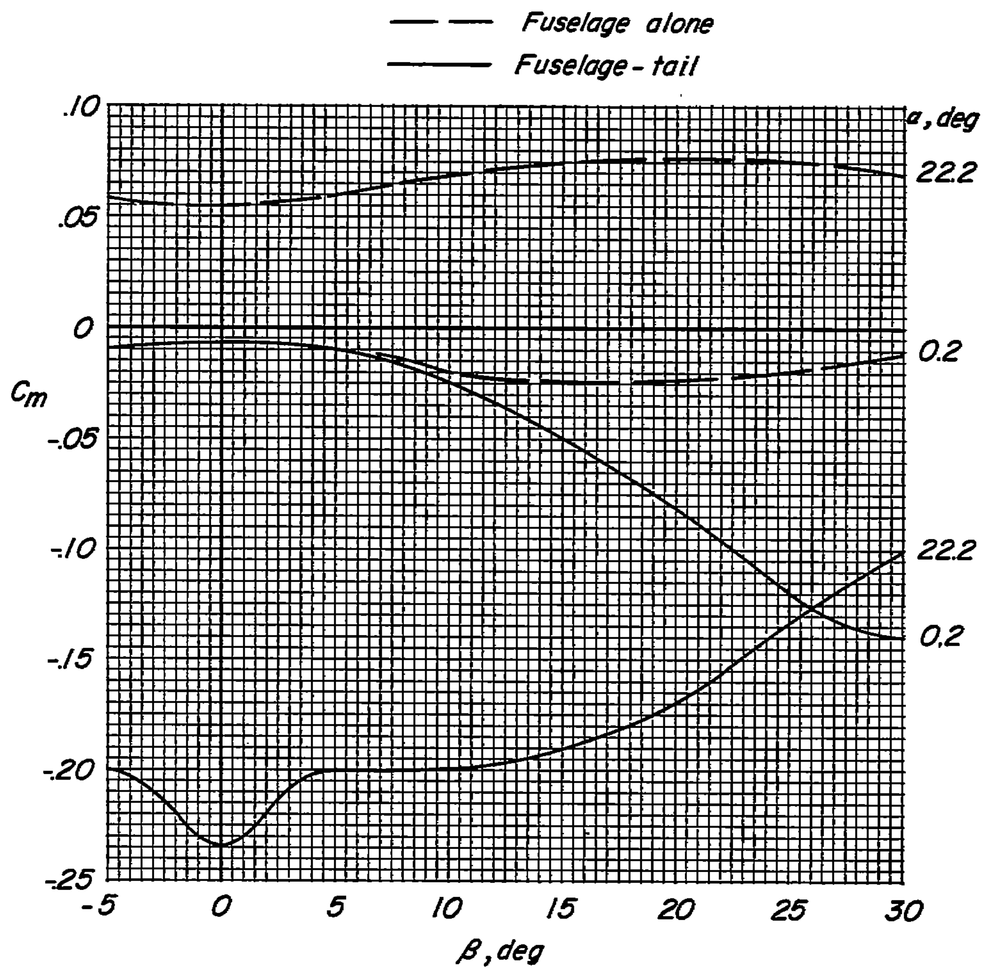


Figure 11.- Variation of pitching-moment coefficient with sideslip angle for a fuselage-tail configuration at low subsonic speeds.

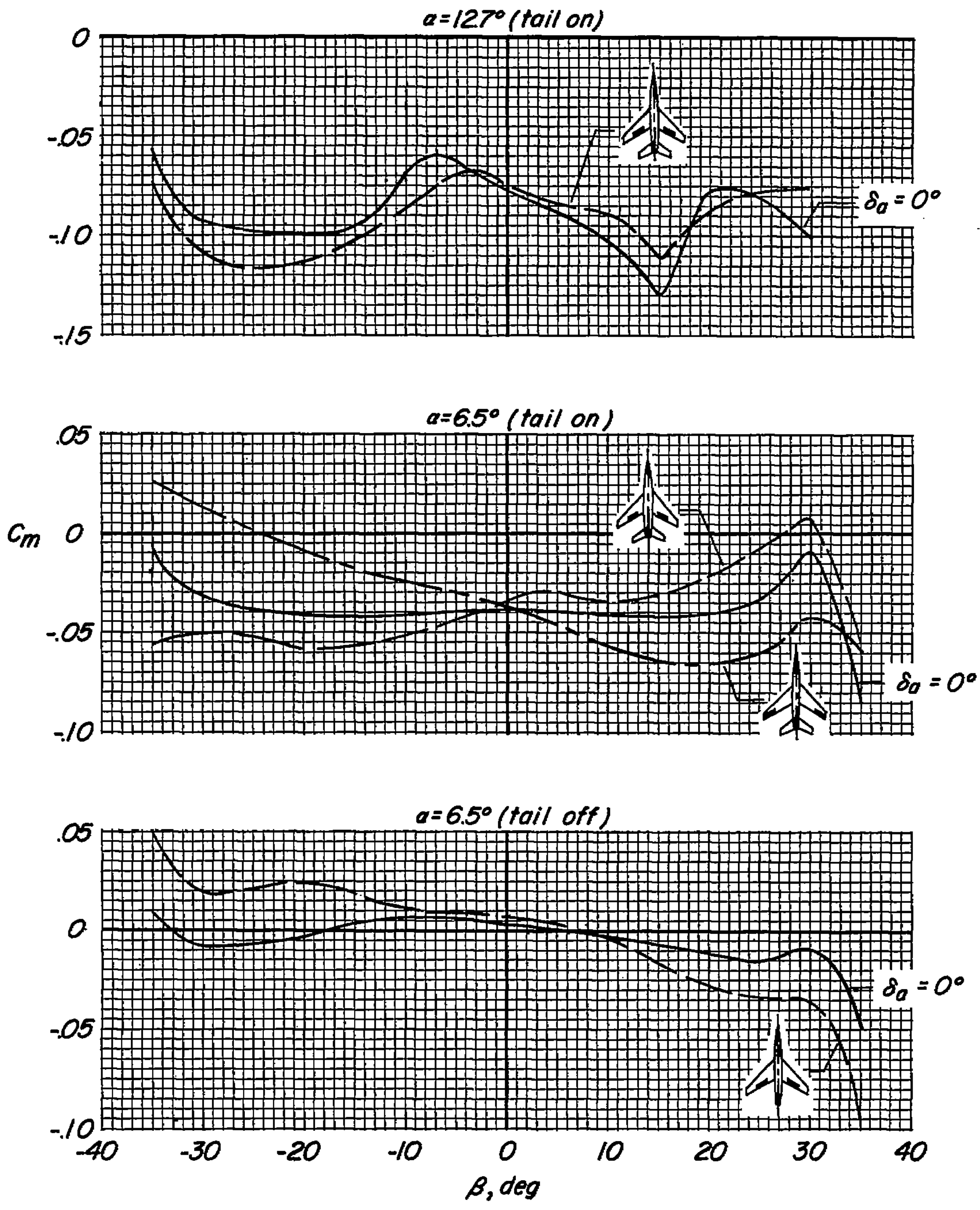


Figure 12.- Variation of pitching-moment coefficient with sideslip angle for various aileron configurations. Right aileron down 10° and left aileron up 10°.

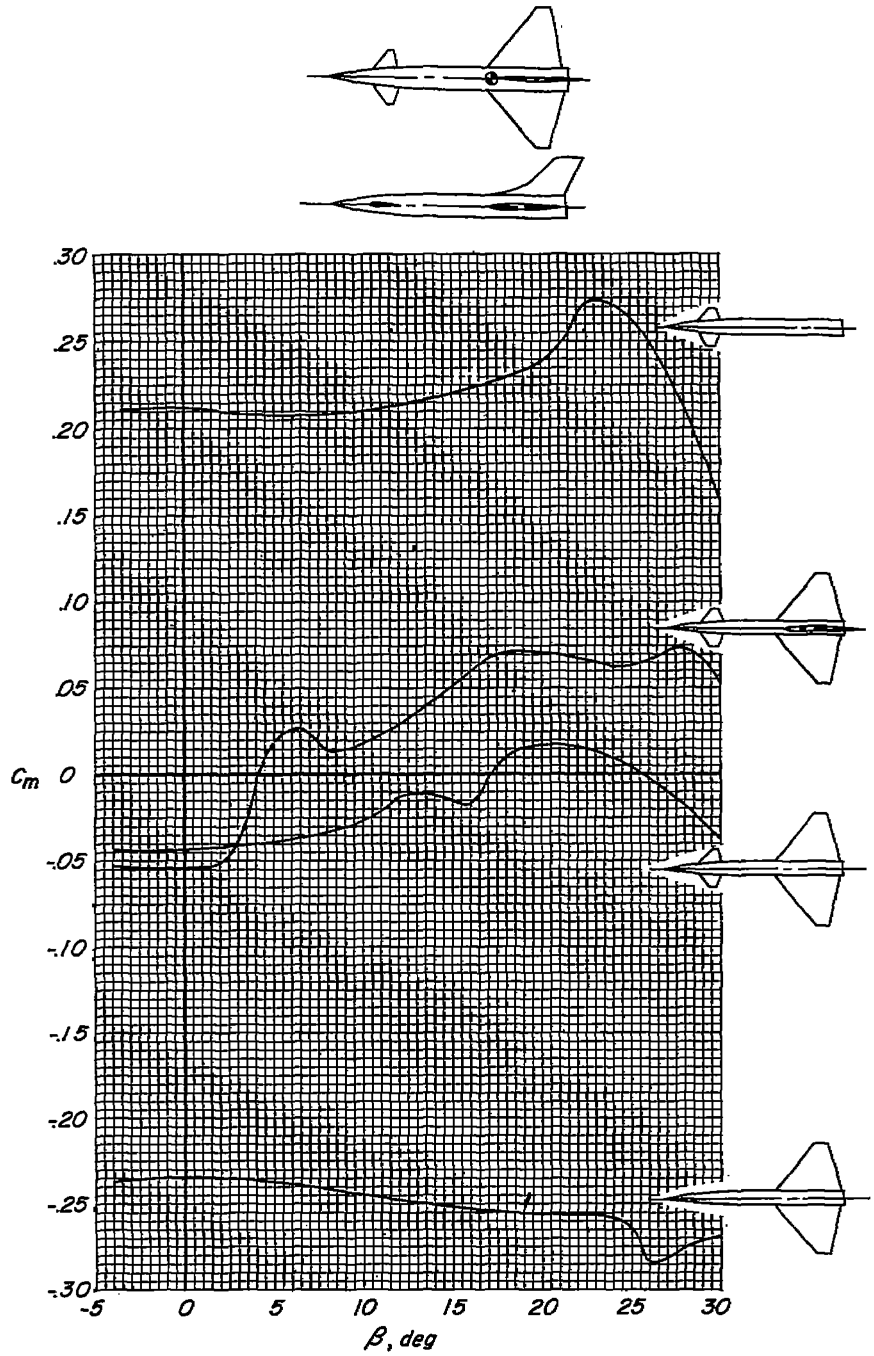


Figure 13.- Effect of canard control on variation of pitching-moment coefficient with sideslip angle at low subsonic speed. Canard-control deflection, 10°; $\alpha = 10°$.